SAMPLE UNIT SELECTION FOR STUDIES OF HERBACEOUS OLDFIELD VEGETATION[1]

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Abstract. The size and number of sampling units needed to sample herbaceous oldfield vegetation must be determined for each situation. Prior to obtaining data for a long-term study of early oldfield plant succession at the Waterloo Mills Field Research Station, Pa. statistical tests and theoretical considerations were evaluated. Of the five sizes of circular quadrats tested, the 0.03125 m^2 size was determined to be suitable to obtain detailed data efficiently and yet sample within the estimated smallest scale of heterogeneity. A sample of 100 quadrats, the minimum number needed to compare frequencies, was determined to be adequate (within 10%) from calculations of the standard error of the mean, running means, and species-area curves. Subsequently, annual samples were obtained at 100 points from a stratified grid of 570 quadrat-center points in each 6.40 x 9.12 m subplot studied.

OHIO J. SCI. 76(4): 185, 1976

The trend toward broad conceptual thinking on the nature of successional plant communities (e.g. Drury and Nesbit, 1973; Horn, 1974; McNaughton, 1974; and Mellinger and McNaughton, 1975) emphasizes the importance of evaluating the adequacy and accuracy of data sets before using them to make sweeping generalizations. The use of quadrats to sample oldfield herbaceous vegetation necessitates decisions as to the size, shape, and number of the quadrats in the sample. The initial experimental design of each investigation should begin with some form of pre-testing to assure the adequacy and accuracy of the sampling methods.

The shape of observational units has long been known to have an effect on the sampled data (Clapham, 1932). Although rectangular, square, and circular quadrats have been used in various vegetational studies, several theoretical considerations favored the use of circular quadrats in the Devon study. The occurrence of a species may be expressed as the probability of occurrence within a given distance (radius of the sample unit) from a random point. Because a basic goal of the Devon Project was to investigate spatial relationships between species, isodiametric quadrats were preferable to insure that the maximum distance between any two species was minimized relative to the area of the quadrat. Circular quadrats required only a single random center-point for location whereas, if square or rectangular quadrats were used randomness would have been sacrificed by orienting all quadrats in a standardized way or else two random points had to be selected: one to locate and one to orient each quadrat sampled. Circular quadrats were preferred for theoretical reasons and it was found that data from the square quadrats did not differ substantially.

The purpose of this paper is to describe the strategy used in sample unit selection for the Devon Project, a long-term study of early oldfield plant succession at the Waterloo Mills Field Research Station at Devon, Pennsylvania. The study was designed from the onset to test succession theory by creating a detailed data base suitable for statistical interpretation.

METHODS

Circular quadrat frames of five sizes (0.5, 0.25, 0.125, 0.0625, 0.03125 m^2) were field tested on a standard 6.40 x 9.12 m subplot of the

[1]Manuscript received October 30, 1975 and in revised form May 17, 1976 (#75-64).

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Devon Project study area (McCormick, 1969) to determine their relative efficiency for sampling herbaceous oldfield vegetation. Of the data obtained, only areal cover values which were recorded by taxonomic species for 15 random quadrats are considered here. Variance: mean ratios and frequency distributions were used to assess the effects of quadrat size on the sample data. Sample size was evaluated by running means (Kershaw, 1964), species-area curves (Cain, 1938), and an estimate of the number of quadrats necessary to obtain a standard error within 10% of the mean. This last measure was calculated using the following formula:

$$n = \frac{s^2}{y}$$

where n is the number of samples required to obtain a standard error within a stated percentage of the estimated mean, y is the observed mean multiplied by the stated percent as a decimal, and s is the standard deviation of the observed mean. The quadrat size judged to be most efficient was tested further by using a second, and larger, sample of 100 random quadrats.

RESULTS AND DISCUSSION

The two larger size quadrats (0.5 and 0.25 m^2) of the series tested required extraordinary care during cover measurements to reduce errors of omission and inaccuracies in the estimation of percent cover. Furthermore, these large quadrats contained so many individuals that several hours per quadrat were often required to make density counts. For these reasons the larger sizes were rejected early in the field testing.

The variance:mean ratios for cover values of the five most abundant species (table 1) were greater than 1.0, indicating a contagious rather than a random distribution (Greig-Smith, 1964). The cover values for 3 of the 5 most abundant species show the lowest variance in the smallest quadrat size and the other 2 exhibit the least variance in the largest size. The variance:mean ratio for the total value for all species is substantially less in the smallest tested quadrat.

Kershaw (1957) and Greig-Smith (1964) have suggested that the use of a basic sample unit, not more than one-half the size of the smallest scale of heterogeneity likely to be present, greatly increases the sensitivity of the sampling. This scale, a function of a pattern in the community (McDonough, 1961), reflects individual clone size, short-distance seed dispersion, and other poorly understood factors such as auto- and exotoxic phytochemical interaction. Prior to our study, observations of fields within the vicinity of Devon suggested that the smallest scale of heterogeneity was approximately 0.0625 m^2. The relatively lower variance of the mean values from the 0.03125 m^2 quadrats presented the expected pattern and thus verified the scale of heterogeneity.

The number of quadrats needed in a sample is a function of the variation between quadrats within the sample (Mueller-Dombois and Ellenberg, 1974). Therefore, an estimate of the number of quadrats necessary to obtain a given degree of variance is a useful measure of the adequacy of a given sample size (table 2). The number of quadrats estimated to give a 10% standard error of the mean, even for the most abundant species, indicates that a large sample, on the order of 100 or more quadrats, is necessary.

TABLE 1

Comparison of variance: mean ratios for cover values based on 15 samples.

	Quadrat Sizes								
	0.03125 m^2			0.0625 m^2			0.125 m^2		
Species	$\bar{X}$	SEM	$S^2:\bar{X}$	$\bar{X}$	SEM	$S^2:\bar{X}$	$\bar{X}$	SEM	$S^2:\bar{X}$
Setaria lutescens (Weigel) Hubb.	27.5	6.4	20.7	27.1	6.6	22.5	29.4	7.9	29.9
Ambrosia artemisiifolia L.	21.0	10.0	66 6	27.3	10.8	60.0	23.1	6.1	23.0
Barbarea vulgaris R. Br.	14.2	3.9	15.1	14.0	3.7	15.2	12.9	4.8	25.1
Solanum carolinense L.	12.9	4.5	22.1	8.1	6.5	73.1	14.8	6.6	42.9
Mollugo verticillata L.	10.7	5.1	33.6	15.3	5.8	31.0	5.9	2.4	13.2
Total (all species)	100.4	10.4	15.1	105.3	14.2	26.7	108.3	13.3	22.9

*Means ($\bar{X}$), standard errors of the means (SEM), and variance:mean ratios ($S^2:\bar{X}$).

TABLE 2

Number of quadrats necessary to give a 10% standard error of the mean.

Species	Quadrat Size		
	0.03125 m^2	0.0625 m^2	0.125 m^2
Setaria lutescens (Weigel) Hubb.	76	83	100
Ambrosia artemisiifolia L.	317	217	99
Barbarea vulgaris R. Br.	104	101	195
Solanum carolinense L.	173	899	306
Mollugo verticillata L.	324	197	223
Total (all species)	14	25	21

Because the research design required the use of frequency as a comparative measure, frequency confidence limits were considered in relation to sample size. These confidence limits improve significantly as sample size increases. Greig-Smith (1964) suggests that a sample size of at least 100 quadrats is needed for adequate calculations of comparative frequency.

Two methods of determining sample size, running means and species-area curve, suggest a sample size much smaller than 100 quadrats. Running means, calculated for cover (and also density, but not presented here), indicated that less than 35 quadrats were necessary to obtain values within 10% of those obtained with 100 quadrats. A species-area curve based on 100 circular 0.03125 m^2 quadrats indicated a sample of 15 to 20 quadrats by the 10% line and a sample of 50 to 55 quadrats by the 5% line. These methods, however, have generally been found to underestimate the number of quadrats necessary for an adequate sample.

There are two basic approaches to the problem of adequacy of sample unit and sample size. The first is concerned primarily with achieving a normal distribution of the data for the species of interest (Rice, 1967); the second works toward sampling the pattern of vegetation at its smallest scale of heterogeneity (Kershaw, 1957). A common way to increase the normality of field data is to increase the size of the sample unit. This has a smoothing effect on the data, but it tends to obscure small scale patterns of heterogeneity and to increase errors of estimation and omission in data collection. On the other hand, a decrease in quadrat size generally decreases the normality of the data but increases the sensitivity of the sampling to small scale changes in community structure as the quadrat size becomes less than the smallest scale of heterogeneity. The choice between these two approaches is weighted heavily by the purpose of the research, and in the Devon Project the latter approach was taken. To improve normality in the Devon data, means of several groups of randomly selected quadrats within each sample were calculated and the central limit theorem was applied. Thus, regardless of the distribution of the individual values, the distribution of the mean values derived from these groups of randomly selected values were normally distributed (Sokal and Rohlf, 1969).

There is no single answer to the question of what is an adequate sample of herbaceous oldfield vegetation. Each new situation must be reevaluated. For the Devon Project the conclusions reached from the field tests and the theoretical considerations presented here lead to the use of circular 0.03125 m^2 quadrats. Similarly, the sample size was based on an annual random sample of 100 points from a stratified grid of 570 quadrat-center points in each 6.40 x 9.12 m subplot.

Acknowledgments. The authors are grateful to Dr. Jack McCormick, past Director of the Waterloo Mills Field Research Station, for providing access to the Devon Project data and for many helpful ideas regarding its analysis and to Dr. Irwin A. Ungar for his critical review of the manuscript. This study was partially funded by The William Penn Foundation, Philadelphia; Jack McCormick and Associates Inc., Devon; The Academy of Natural Sciences of Philadelphia, Pa. and Ohio University, Athens, Ohio.

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